Program Structures & Algorithms
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GROUP ASSIGNMENT

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Abstract

We implemented MSD (most significant digit) radix sort to compete with other sorting algorithms to sort random Chinese characters. In the early study of radix sort, we expect it to be the fastest to sort Chinese character. As one of non-comparison sort, MSD radix sort has advantages compare with other sorting algorithms by handling string of variable length and it can order a string prior to scan the entire of the string. However, unlike English word can be order by English alphabet, to order Chinese character is quite complex. As we investigated both sorting Chinese characters (Pinyin) in English alphabet order and Chinese character in Pinyin order. We demonstrated three alternative implementation of MSD radix sort to sort Chinese character as we eager to find the most comparative one in terms of time complexity among other sorting algorithms.

1 INTRODUCTION

There are lots of great sorting algorithms developed throughout the years, yet no optimized algorithm that beats other algorithms in any circumstances. In java, String is a reference type which contains strings or list of characters; with different encoding methods such as ascii and Unicode, there are huge numbers of characters from different languages that can fit in the String object. Sorting strings in alphabets is a popular and even standard way to demonstrate how good an algorithm is, since alphabets can be transferred into numbers which has a natural way of ordering. we are trying to come up an alternative MSD radix sort to sort the strings which contains Chinese Characters.

2 BACKGROUND

It is quite challenging to count the numbers of Chinese characters, since they are transformed from the old oracle bone script. Moreover, there are about fifteen thousand Chinese characters. For comparison, since the Chinese characters have a lot of elements in it, like strokes and Pinyin the official way of sorting is by Pinyin first, then number of strokes if they have the same Pinyin and there is a certain order of strokes if two characters have the same number of Strokes. Other than that, since one single Chinese character may have multiple tones for different cases, it's extremely hard to have a best order for Chinese characters.

Figure 1 Four Different Chinese tones

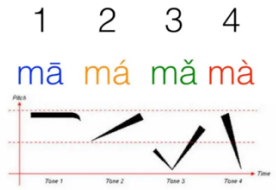


Figure 2 Chinese character with different tones

For this project, we are following the Collator from *IBM.ICU* which produced a Key of Chinses characters in Pinyin order. Since the computer would only store zeros and ones, there are lots of encoding method, typically Chinese Characters are encoded as Unicode, and that's where we start. After examining the input, *shuffledChinese.txt* we believe it's a one million lines of unique Chinese strings with two to three characters each and that's also what we want for testing, a random array.

3 DISCOVERING

3.1 UNICODE

After testing, we found the Unicode doesn't follow the correct order. As shown in Fig. 3, since Pinyin for *"曹玉德"* is *CAOYUDE and Pinyin for "刘持平"* *is LIUCHIPING* according to the rule; C is supposed to be in front L, but neither UTF8 nor UNICODE demonstrate that. "E6" with "E5" and "u6" with "u5" is contradicted for the order. So, we move on.

Figure 3 Conversions of Chinese Characters

```
          刘持平                曹玉德                许凤山
PINYIN:  LIUCHIPING             CAOYUDE              XUFENGSHAN
UTF8:    E58898E68C81E5B9B3, E69BB9E78E89E5BEB7, E8AEB8E587A4E5B1B1,
UNICODE: \ufeff\u5218\u0631\u5e73, \ufeff\u66f9\u7389\u5fb7, \ufeff\u8bb8\u51e4\u5c71
```

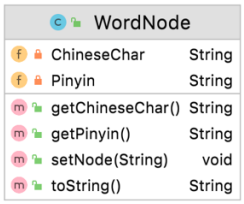
3.2 SYSTEM INFORMATION

Model Identifier:	MacBookPro16,2019
Processor Name:	8-Core Intel Core i9
Processor Speed:	2.3 GHz
Number of Processors:	1
Total Number of Cores:	8
L2 Cache (per Core):	256 KB
L3 Cache:	16 MB
Memory:	16 GB

3.2 SORTING IN PINYIN

Since Pinyin is one crucial part with sorting Chinese characters, we are thinking to convert the Chinese character into Pinyin, sort them and then convert back to Chinese characters afterwards.

Figure 4 class diagram for WordNode



We are using the *PINYIN4J package from BELERWEB* for transform the characters into Pinyin then sort them by Husky sort, Tim sort, Dual-Pivot Quick sort, MSD, and LSD radix sort algorithm. Since these algorithms can compare the integers naturally (each alphabets have its unique ASCII integer), Fig. 5 shows is our workflow.

Figure 5 MSD radix word node implementation

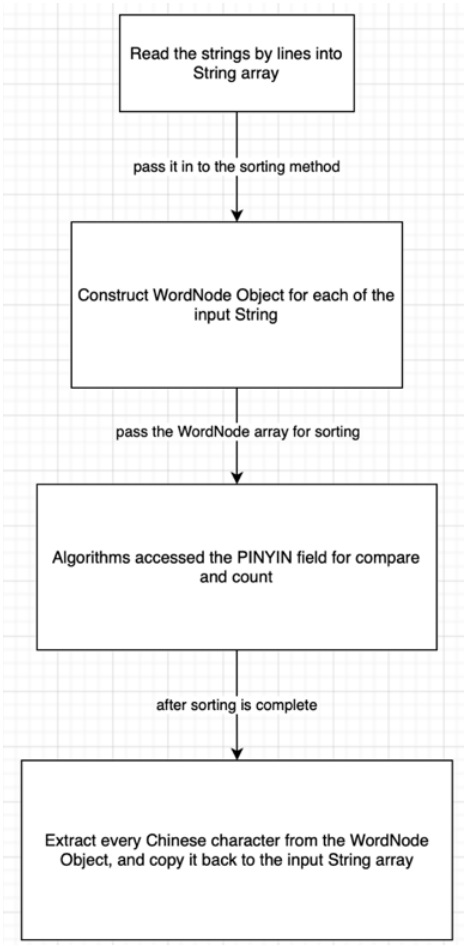
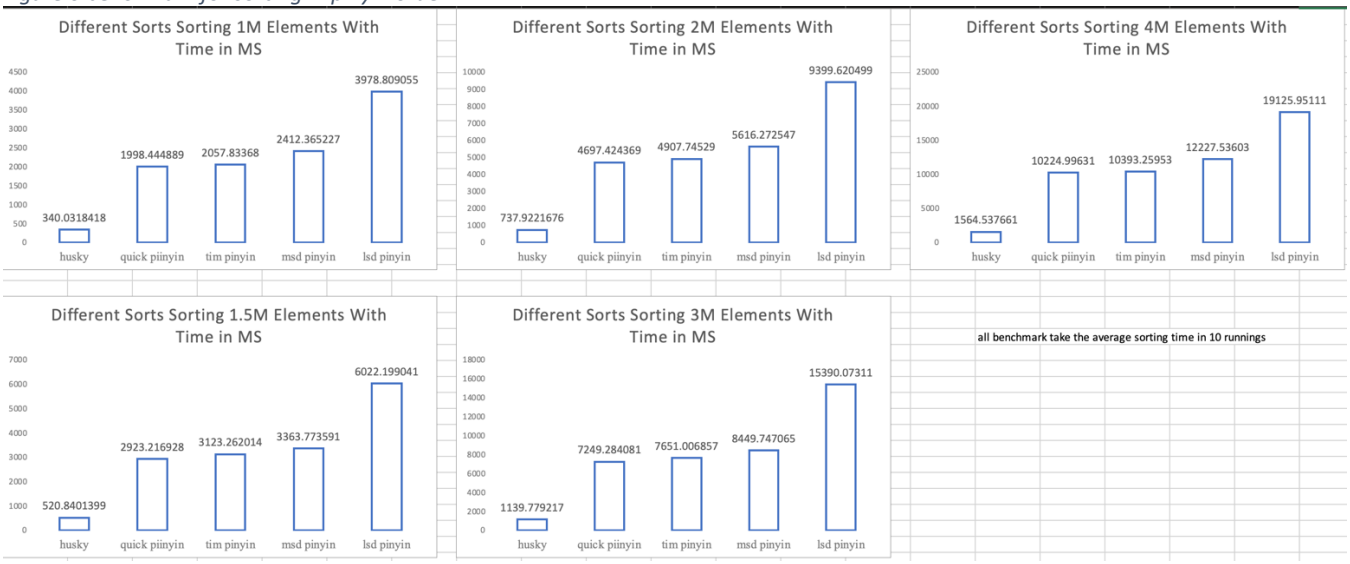


Figure 6 benchmark for sorting in pinyin order



As shown in the graph, we have implemented five different methods, and this is the benchmark of them. As the husky sort dominate the sorting result, other sorts give reasonable benchmark result. Since there are radix sort included, here is the distribution numbers of different length of Pinyin from the input. Since we alter the LSD sort to make it can sort alphabets in different length, the formula for LSD and MSD would become $W(N+R)$ and $N+R$ for MSD in best cases. Best case for MSD is nearly never going to happen since with one million inputs, the first digit would be only unique for 26 strings, so we disregard it. According to the formula, we have R = 256 since all alphabets can be represent in ASCII in 256 numbers. W = 17 for the LSD sort and W = 9.3 for MSD sort, the average number of widths as shown in Fig. 7. Since the W is the only variant for LSD and MSD, we can valid this by observe a nearly double time for LSD compared to MSD. Both Dual pivot quick sort and Tim sort provides $Nlog_2N$ just with different constant which won't affect a lot, that's explained why they performed about the same in the graph.

Figure 7 length of Pinyin distribution among 1M input Chinese Characters

```
3 102
4 8543
5 28945
6 54565
7 82746
8 135177
9 196858
10 213691
11 161181
12 83758
13 27861
14 5691
15 728
16 124
17 30
```

There is one thing get our attention that MSD is slower than the quick and time sort, by time complexity, it should beat the other two by 9(N+256) ($W(N+R)$ versus N*19 ($N*log_2 1000000$); at least for the one million elements case since it have no repetitive elements. Maybe it's because the ways we implement MSD or the hidden constant factor before every time complexity, and quick usually have the smallest constant factor.

3.3 PROBLEM WITH SORTING BY PINYIN

However, we found out some problem with compare Pinyin in Chinese Characters. Firstly, the stable and not-stable sort like Tim sort and quick sort, they have different output since there are a high chance

that Chinese characters have the same Pinyin, so with different stability, the output varies. Secondly, if we combined Pinyin together, it breaks the rules by compare Pinyin one by one instead of characters. Like Fig. 8 shows, by rules, we should compare *"阿"* and *"阿"* and then *"鼎"* and *"迪"*; but with Pinyin, it can't distinguish between Chinese characters other it compares Pinyin characters instead. Then by Pinyin *"N"* is before *"Y"* so does the Chinese characters, but by right rules we know that this comparison shouldn't even happened since it's not compared the Pinyin with the Chinese characters with same index. That's where we come with the next algorithm, the byte array.

Figure 8 example of Chinese character and their PINYIN

阿鼎	阿迪雅
ADING	ADIYA

3.4 SORTING BY BYTE ARRAY

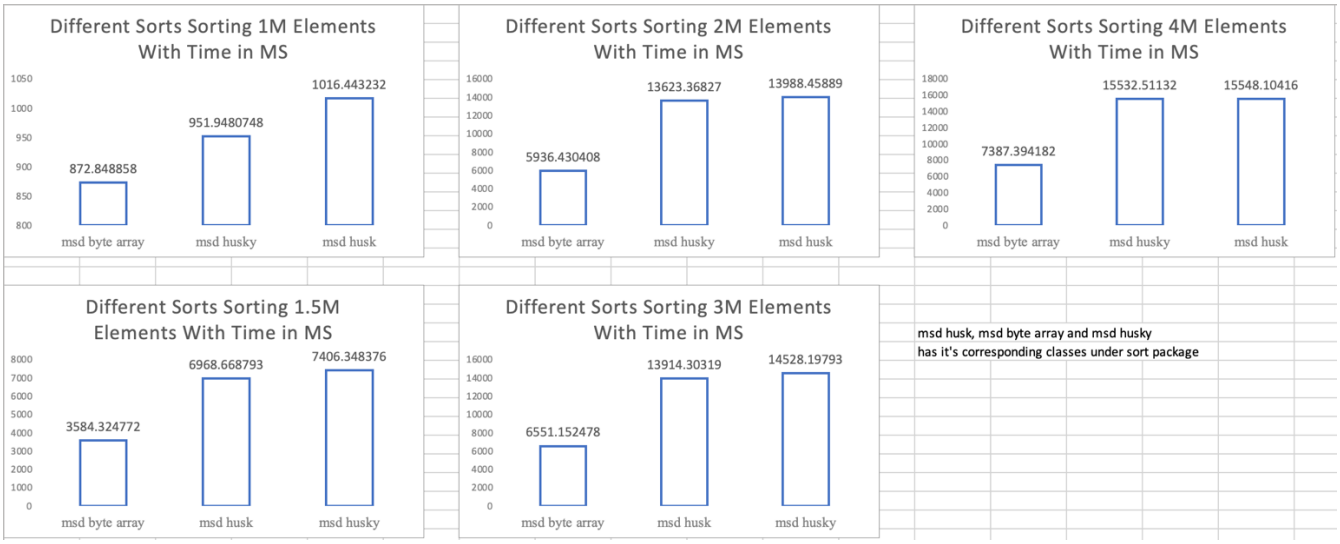
After wondering a lot, we get inspired by husky sort, after reading the paper for husky sort, we come with the idea that convert the Chinese characters into primitives, with the faster compare time and maybe less times of comparison, we may have better performance for the algorithms. We initially want to learn the idea of convert Chinese characters into long just like husky did, but we just can't come with the long number that is unique for each character and follow the same order of the original character. Then with the help of the Collator, we found out there is a *toByteArray* function where it can transfer the Chinese characters into byte array with correct locale, and here is where our algorithm starts. Start with the data, since we are sorting the byte array instead of string (character array), they have their unique length distribution as the Fig.9 shows. The W = 10.6for MSD and W = 11 for LSD.

Figure 9 length of byte array distribution among 1M input Chinese Characters

8	947
9	164411
10	1394
11	833248

We initially come with the idea to combine the byte array and the byte array from Chinese characters in Unicode (UTF-8) and sort them by every byte, and then convert the last part of the byte array, which is the original Chinese character in UTF-8 back to the characters. With MSD husky to have a fixed size byte array after the combination and MSD husk have a variant size byte array after combination. However, this idea didn't work properly since there are some conversion issues with UTF-8 code back to Chinese characters. Finally, we come up with our final optimization, the MSD byte array, which is the leading algorithm in the chart.

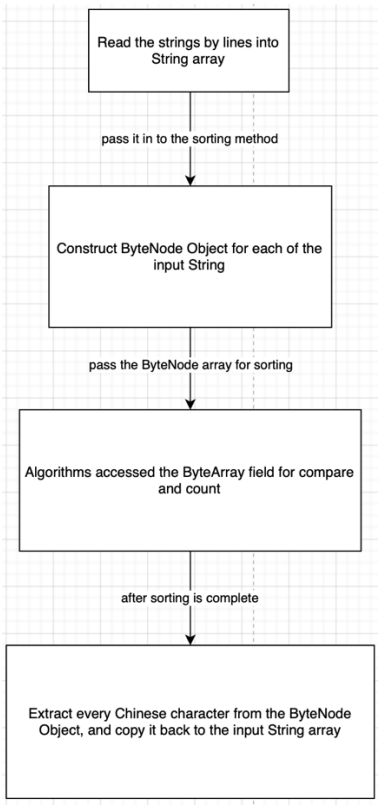
Figure 10 benchmark for sorting in byte array order with first attempt, MSD husky and MSD husk



3.5 SORTING BY OBJECT WITH BYTE ARRAY

Our Byte array method can be examined by Fig.11 which shows the flow.

Figure 11 MSD radix byte node implementation



After we construct the byte array object, every time MSD and LSD byte array method ask for the count array position, we return the corresponding int that convert from byte and -1 if it's a shorter array; we also flip the sign of the byte array since we don't want negative index for the array.

Figure 12 class diagram for ByteNode

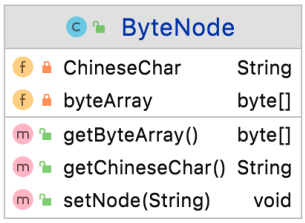


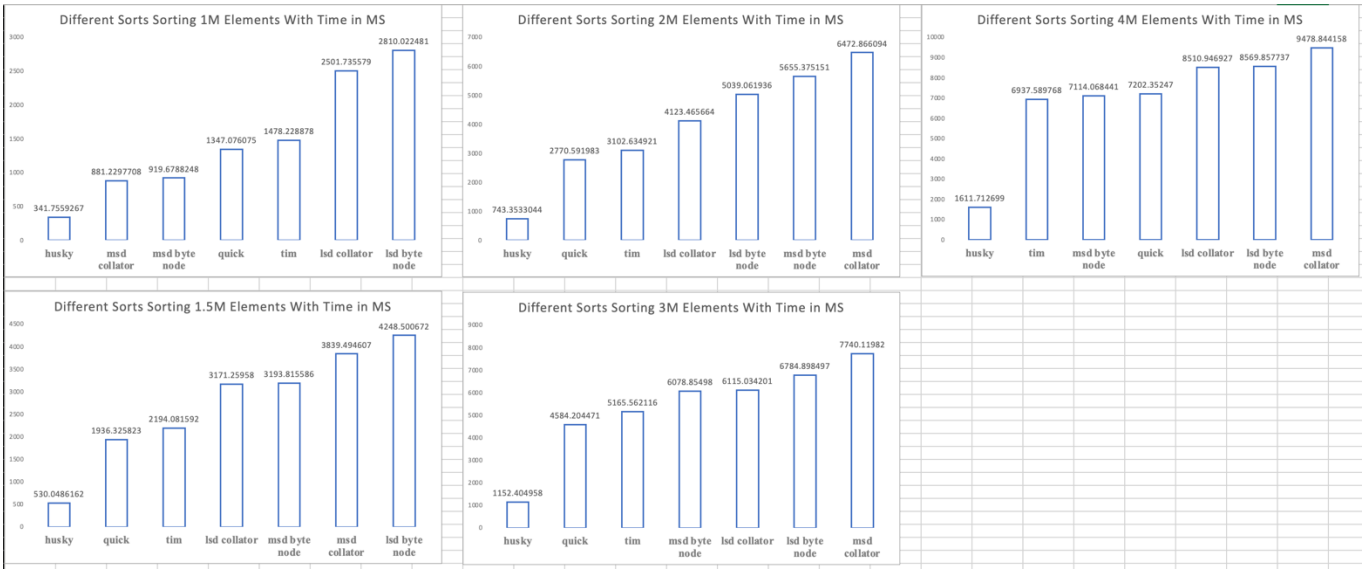
Figure 13 method to return the current byte

```
public int byteAt(ByteNode s, int d)
{
    if (d < s.getByteArray().length) return s.getByteArray()[d]&0xFF;
    else return -1;
}
```

Figure 14 method to get the byte array from original Chinese characters

```
public static byte[] toByteArray(String string){
    return collator.getCollationKey(string).toByteArray();
}
```

Figure 15 benchmark for sorting in byte array order with other sorting algorithm



As shown in Fig. 15, here's our result. It's worth mention that Tim and Quick sort is using the collator.compare(String, String) method for compare and it's just different than comparing byte array, but since they came with the same result, we also benchmark them for comparison; and just for fun, we put CollationKey as the object instead of ByteNode to see if there are any differences, CollationKey and ByteNode basically have serve the same purpose of compare the byte array field and store the original Chinese characters. As expected, since we reduce the W for LSD, the longest length of the key (17 to 11), the result increase from Pinyin method, although we have increase R by hundred, since byte goes up to 128 where character only goes to 26, R plays a small factor in formula W(N+R), which should not affect a lot. There is something we want to emphasis that we discover from the graph.

1. For the comparison between MSD byte array and LSD byte array. (Text below will call MSD and LSD respectively). MSD generally are better than LSD, when it only takes the average length as W, and it has a perfect N+R run time if the input is all unique in the first index. That's the reason we believe in 1M comparison, MSD beat LSD. The MSD wins the competition by its average time complexity for random array $Nlog_{128}N$ which is about 3N versus about 11(N+R) for LSD. Then with the number of inputs goes up, the MSD start to lose the huge advantage and sometimes lost to LSD. After lots of thinking, we figured out that's because the input; we just simply copy the 1M array again to achieve 2M and same thing for 3M and 4M. With critical cases, each byte array is guaranteed to appear **FOUR TIMES** in the array and that's what slow down the MSD, since MSD must go through all the bytes and building more and more subarray for the recursion.

2. Through the benchmark, we realize that for 1M input, the MSD is superior for most sorting, then for 1.5M and 2M, it slows down, we think that's because the inputs are not unique anymore since we just copy the whole array, then start from 3M, the difference between the MSD and the two well-known sort, Quick and Tim starts to decrease. Finally, the MSD reaches the same performance as Quick and Tim during 4M input. We believe that's because the MSD is O (W(N+R)) where for Quick and Tim, the average is O ($NlogN$), so at some point, N = 4M in our case, is the break-even point for MSD and $NlogN$ time complexity.